RADIOLOGICAL AND CHEMICAL TECHNICAL SUPPORT CENTER

HUNTERS POINT ANNEX -- Parcel E

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DISCLAIMER

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ABSTRACT

Three soil samples (A, B, and C) from the Hunter's Point Annex, Parcel E, were received at the U.S. Environmental Protection Agency's National Air and Radiation Environmental Laboratory (NAREL) in July 1993 for preliminary study to determine their particle-size and radionuclide distribution, as well as their radionuclide content. Based on conclusions and recommendations of this study, ten more samples (D-M) were collected in September 1993 and sent to NAREL for study to obtain a better understanding of the distribution of radium-226 in the soil and to attempt to determine to what extent soils at the site are contaminated beyond easily identifiable radium point sources.

The following conclusions are based on the results of these studies:

(1) The particle-size distributions of soil samples A, B, and C (Tables 3-1, 3-2, and 3-3), collected in July 1993, and D-M (Table 3-4), collected in September 1993 are similar. Approximately 80 to 90 percent by weight of the particles are in the sand-to-gravel size fractions, about one-third being gravel material.

(2) Soil samples A and C contain elevated concentrations of radium-226 (Tables 3-1 and 3-3, respectively) distributed evenly among the particle-size fractions. In contrast, sample B contains background concentrations (1 to 3 pCi/g) of radium-226 once the identifiable radium source was removed.

(3) Eight of the ten soil samples in the second set of samples (D-F and I-M) contain background concentrations of radium-226. Sample H, taken at an identified source location, contains an elevated radium-226 concentration. Sample G, taken 5 ft away from the location of sample H, contains the highest concentration of radium-226 (Tables 3-7 to 3-16). The activity in both samples is mostly in the smaller-sized fractions, indicating some release of contamination from a source(s) possibly by fragmentation and/or oxidation of the source(s).

(4) Based on the background concentrations found in eight of the ten samples collected near point sources, a significant volume of the Parcel E soil may contain only background levels of radium-226.

(5) Overall, the limited number of samples considered in these studies suggest that a significant volume of the Hunter's Point Annex, Parcel E site could potentially be remediated by a combination of selective removal of soil in the vicinity of identifiable sources and removal of the source from the soil by particle-size separation.

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1.0 INTRODUCTION

Naval Station Treasure Island, Hunter's Point Annex, formerly the Hunter's Point Naval Shipyard, consists of 965 acres within the Hunter's Point peninsula on San Francisco Bay (DEA94) (Figure 1-1). After World War II, the Naval Radiological Defense Laboratory (NRDL) used the area to decontaminate and dispose of ships that participated in nuclear weapons tests at the Bikini Atoll. The NRDL also conducted numerous radiological studies during that time. In 1991, elevated gamma activity was discovered in one landfill, Parcel E, along the southern shoreline of the peninsula (Figure 1-2). The source of contamination was attributed to luminous radium dials, metallic discs (buttons) approximately 1 to 1-1/2 inch in diameter, glass beads, approximately 1/2 inch in diameter, and possibly small flakes of oxidation products from the weathered discs and fine-grain glass material from crushed beads (Figure 1-3). The total volume of contaminated soil is estimated to be between 40,000 and 120,000 yd^3, although most contamination may be essentially point sources within that volume.

This study was conducted by the NAREL through its role as a Superfund Technical Support Center (TSC) to determine if the Parcel E landfill is a candidate for remediation using soil washing/particle-size separation techniques commonly used in the mineral processing industry.

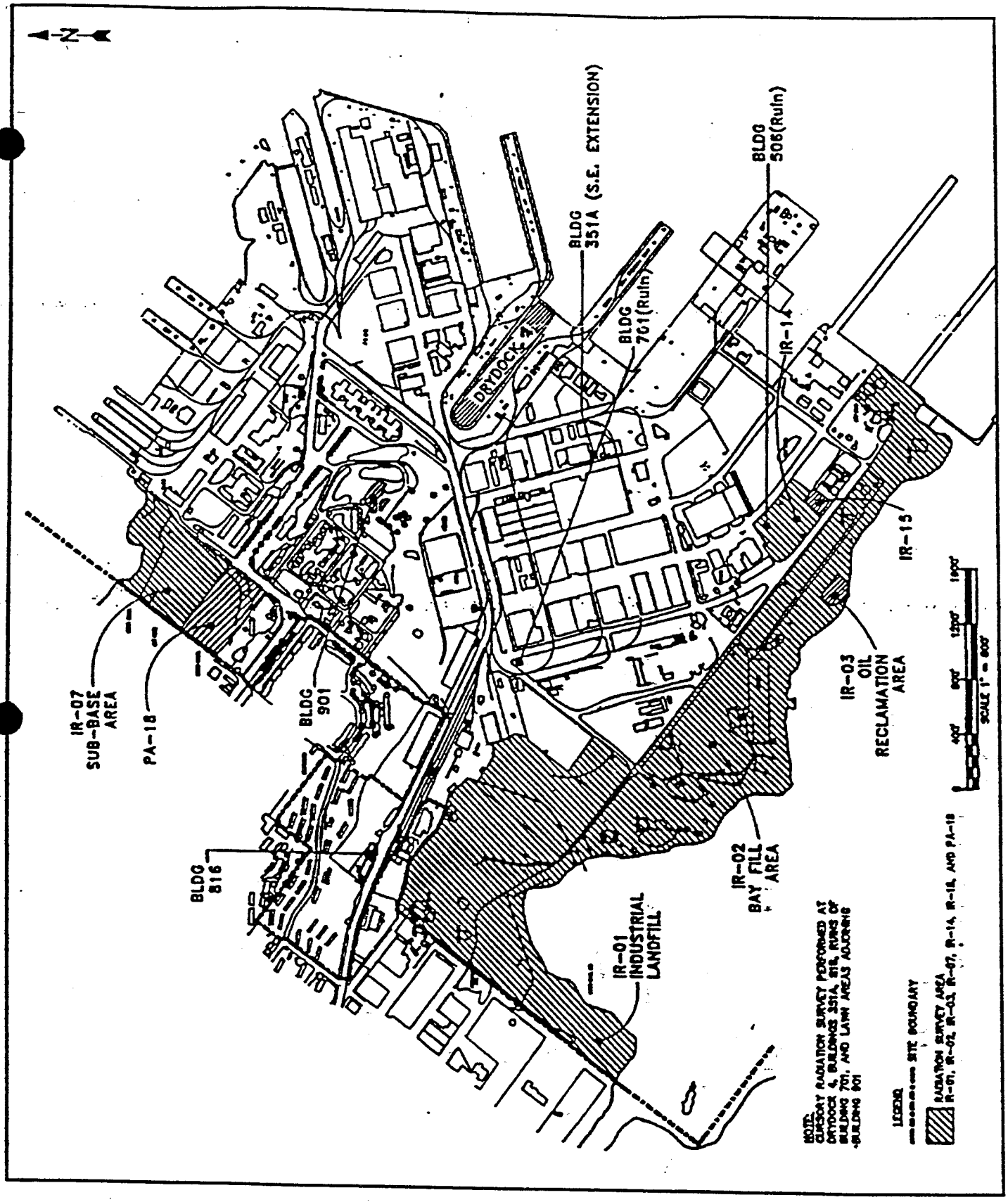

Figure 1-1 Hunter's Point Naval Shipyard

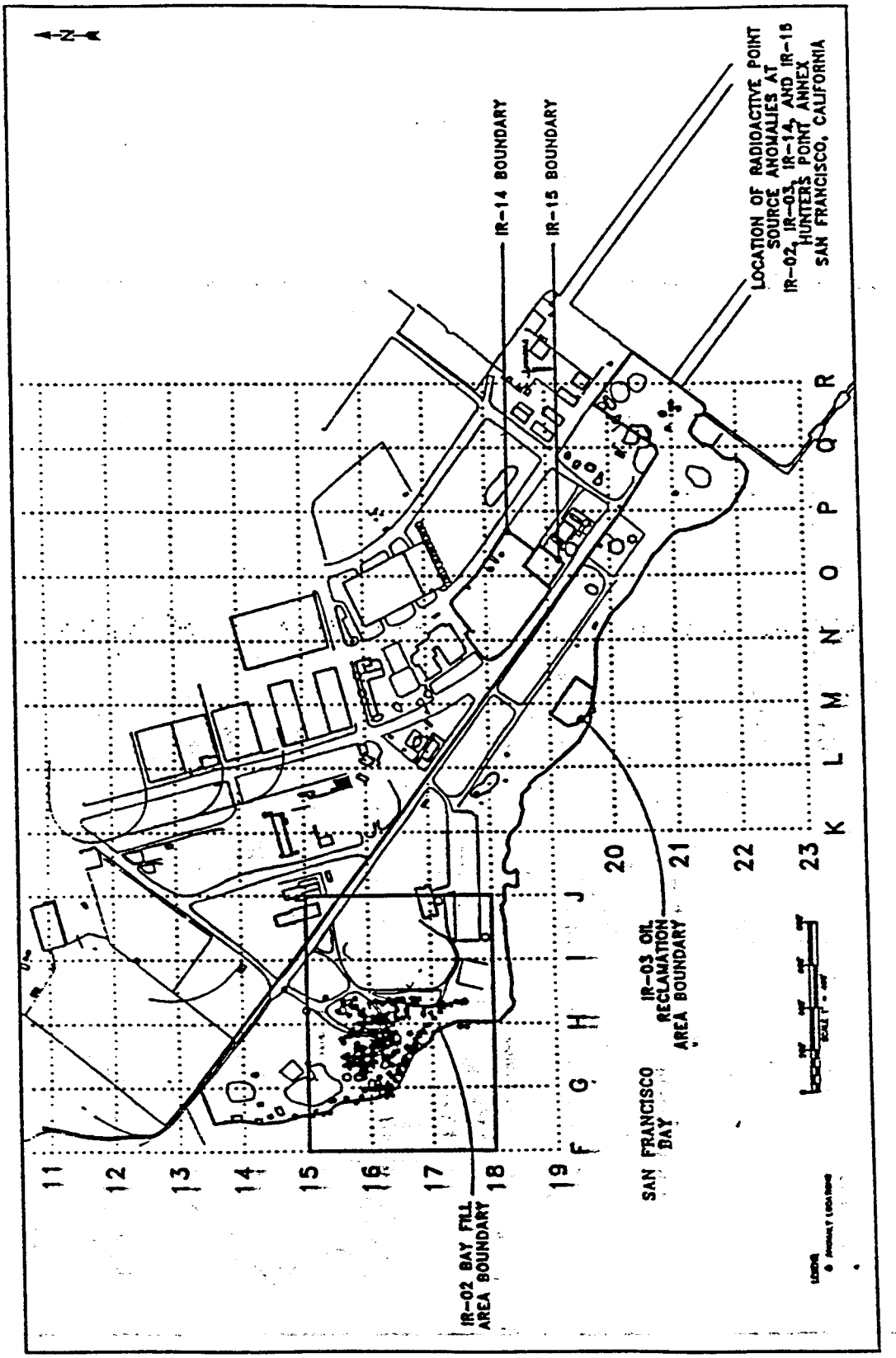

Figure 1-2 IR-02 Bay Fill Area

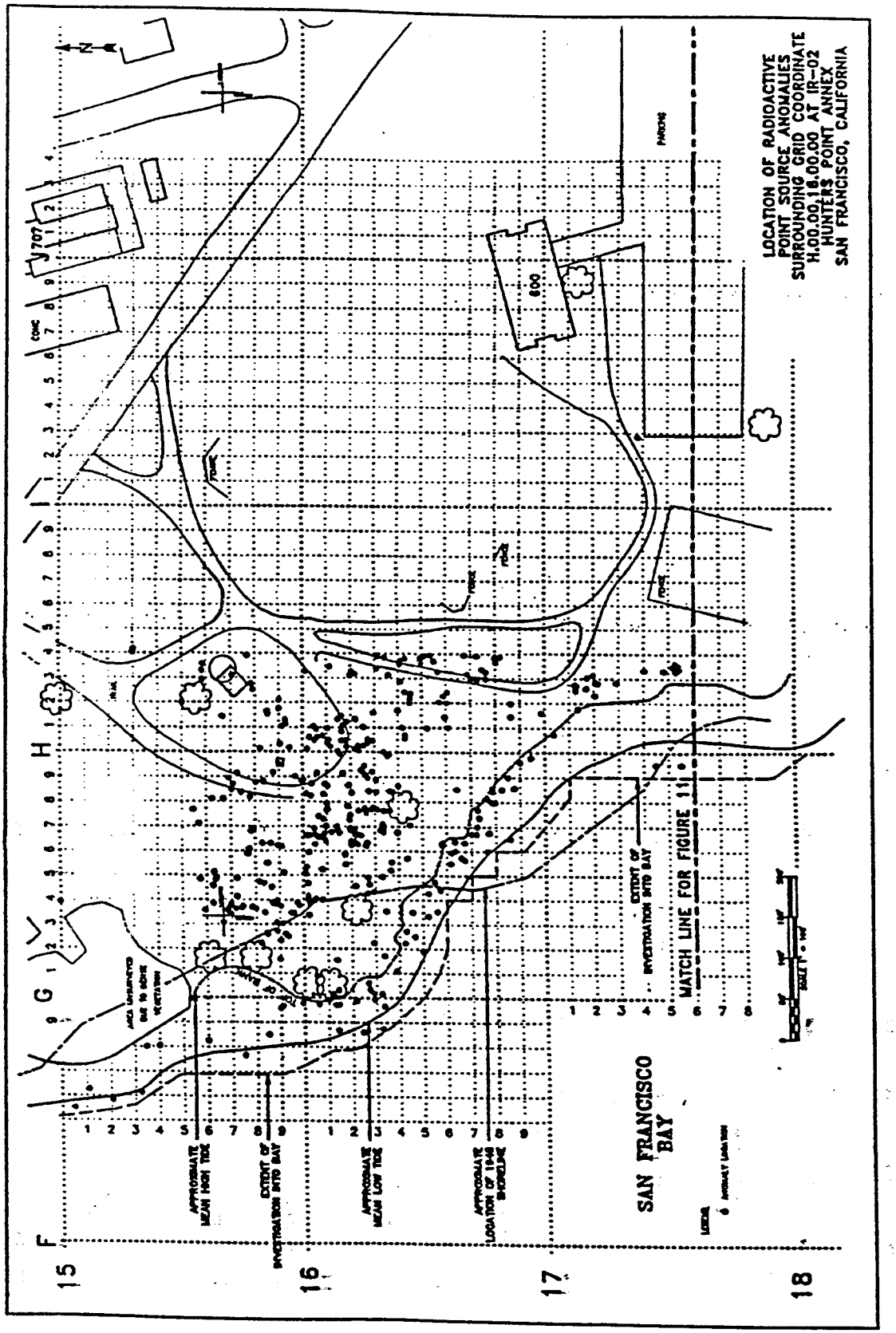

Figure 1-3 IR-02 Bay Fill Area - Identified Point Source Anomalies

2.0 EXPERIMENTAL

2.1 Soil Sample Collection

2.1.1 Soil Samples A, B, and C

Soil samples A, B, and C were collected from the Hunter's Point Annex, Parcel E, by U.S. Environmental Protection Agency (EPA) Region 9 personnel in July 1993.

2.1.2 Soil Samples D-M

Ten additional soil samples (D-M) were collected by SC&A personnel in September 1993. The geographical location, exposure rate at the point of collection as well as points where samples A, B, and C had been collected previously, and general description of each location relative to others or to samples A, B, or C were recorded. The samples were collected from the surface to depths of 2 ft with a shovel and placed into a container similar to a paint can for shipment to NAREL.

2.2 Sample Preparation

In July 1993, NAREL received three 3-kg soil samples for this study, designated samples A, B, and C. Ten additional samples were received in September 1993 and designated samples D-M. The samples were initially screened for gross beta/gamma activity using a Geiger/Muller tube. After initial screening, each sample was weighed, dried at 60°C, reweighed, thoroughly mixed, and then split into homogenous 400-mL aliquots. Each aliquot from the soil samples was then analyzed by gamma spectrometry (see Section 2.6).

2.3 Pre-Sieving Sample Treatment

2.3.1 Soaking

Before sieving, each 400-mL aliquot of soil samples A, B, and C was soaked in water for 12 hr. The samples were soaked for the preliminary study instead of vigorously washed (the typical pre-sieving treatment) in an attempt to minimize fragmentation of a source or parts of a source.

2.3.2 Vigorous Wash

Before sieving, each 400-mL aliquot of soil samples D-M was vigorously washed in water for 30 min at a rotational velocity of 350 rpm and a liquid-to-solid ratio of 4 mL/1 g (SCA91a). The vigorous washing process liberates smaller particles from larger particles and reduces the size of colloidal material.

2.4 Wet Sieving

After either soaking or vigorous washing, the soil sample was fractionated according to size using ASTM standard sieves (SCA91b). The D-M aliquots were separated into size fractions at 6.35 mm (¼ in), 2.00 mm (8 mesh), 1.19 mm (16 mesh), 0.50 mm (30 mesh), 0.25 mm (60 mesh), 0.15 mm (100 mesh), and 0.074 mm (200 mesh). The resulting fractions were dried at 60°C and weighed. The +¼-in, -¼-in/+8, and -8/+16-mesh fractions of each soil sample were individually combined to produce a single +16-mesh fraction; similarly, the -16/+30, -30/+60, -60/+100, and -100/+200-mesh fractions were combined to produce a single -16/+200-mesh fraction. The combined fractions and the -200-mesh fractions were analyzed by gamma spectrometry (Section 2.6). The A-C aliquots were similarly treated, but 1-in (25.4-mm) and 400-mesh (0.038-mm) sieves were included. A highly active source, approximately 1 inch in diameter, contributed virtually all the activity to one aliquot of sample B (second aliquot in Table 3-2). This point source was manually removed before sieving. Each fraction was dried at 60°C, weighed, and analyzed by gamma spectrometry (Section 2.6).

2.5 Wash Water

Water from the vigorous wash and sieving procedures for each sample was collected and a Percol 788N flocculant was added to settle suspended solids. The water was then filtered under pressure through a 0.025-mm pore-size paper filter. A representative sample of the filtered wash-water from each soil sample was analyzed for radioactivity by gamma spectrometry prior to discharge.

2.6 Gamma Spectrometry

Aliquots of whole soil, particle-size fractions, and wash water were analyzed for gamma emitting radionuclides by counting for 1000 min on high-purity germanium detectors (EPA80a).

3.0 RESULTS

3.1 Soil Samples A, B, and C

The preliminary results from the sieving study of three soil samples (designated A, B, and C) from Hunter's Point Annex, Parcel E, were presented in a memorandum to NAREL in August 1993. Each sample was prepared for wet sieving by soaking in water for 12 hr, instead of vigorous washing, to prevent fragmentation of radium-226 sources. The samples were then wet sieved using a nest of nine sieves (1 in, ¼ in, 8 mesh, 16 mesh, 30 mesh, 60 mesh, 100 mesh, 200 mesh, and 400 mesh) and analyzed by gamma spectrometry to determine their radium-226 concentration. The results of these tests are presented in Appendix A in Tables 3-1, 3-2, and 3-3 for samples A, B, and C, respectively. The radionuclide content for combined fractions of samples A, B, and C was calculated from data in Tables 3-1, 3-2, and 3-3, respectively, and summarized in Table 3-5. The data are presented graphically in Figure 3-1, 3-2, and 3-3. The water from wet sieving the three soil samples contained less than the minimum detectable concentrations (MDCs) of radium-226. The MDCs were 98, 83, and 97 pCi/L for water from soil samples A, B, and C, respectively, which are below the acceptable limits for release into the sanitary sewer.

3.2 Soil Samples D-M

After reviewing the results obtained from samples A, B, and C, ten additional samples were collected, as described in Section 2.1.2, in an attempt to obtain a better understanding of the general distribution of radium-226 in the soil of the Parcel E area and to determine if a source or source fragment could be identified in the larger soil fractions (>16 mesh, 1.19 mm).

3.2.1 Particle-Size Distribution

Each soil sample was vigorously washed and wet sieved using a nest of seven sieves (¼ in, 8 mesh, 16 mesh, 30 mesh, 60 mesh, 100 mesh, and 200 mesh). The particle-size distribution results are presented in Table 3-4 in Appendix A.

SOIL SAMPLE A

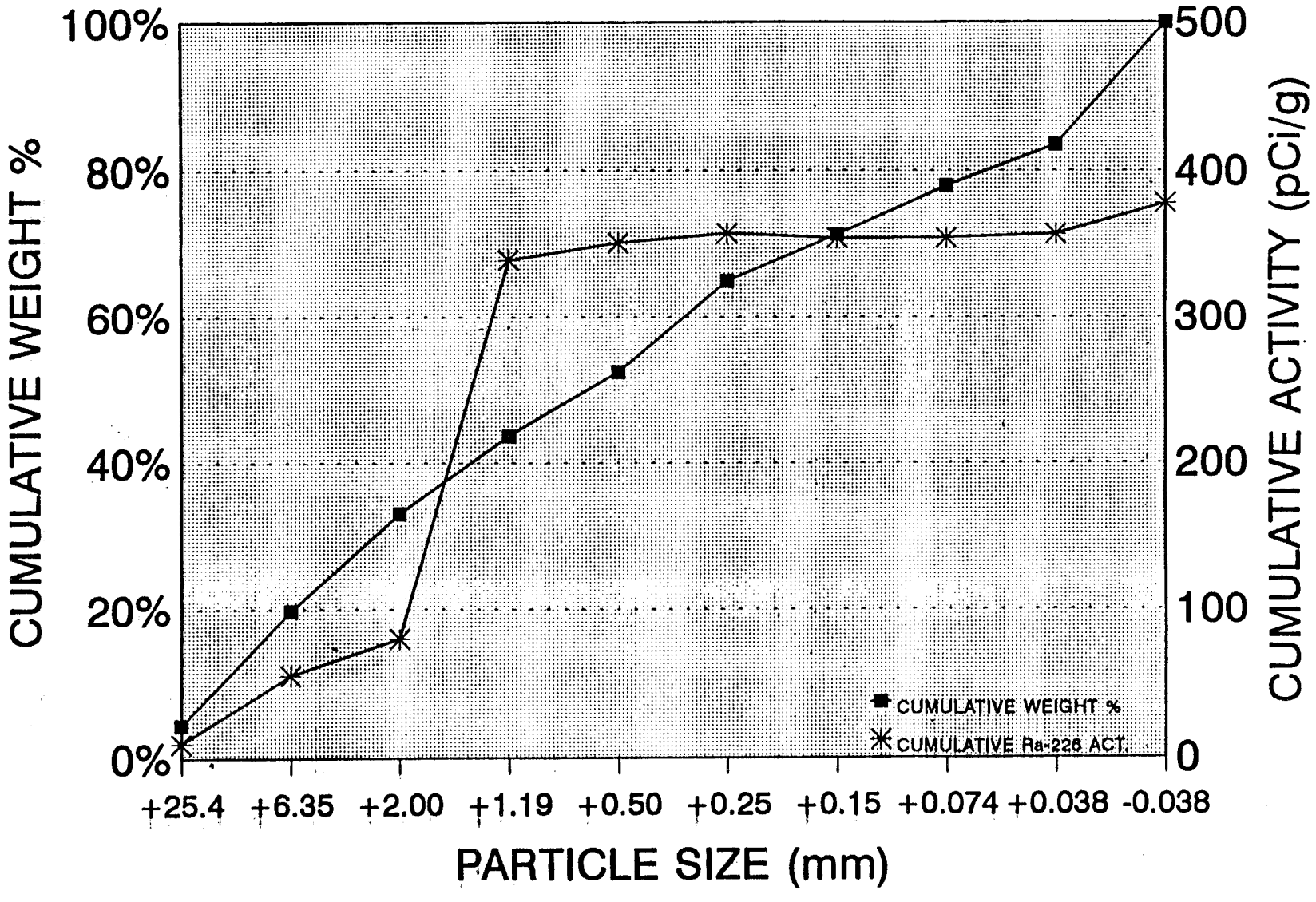

FIGURE 3-1

SOIL SAMPLE B*

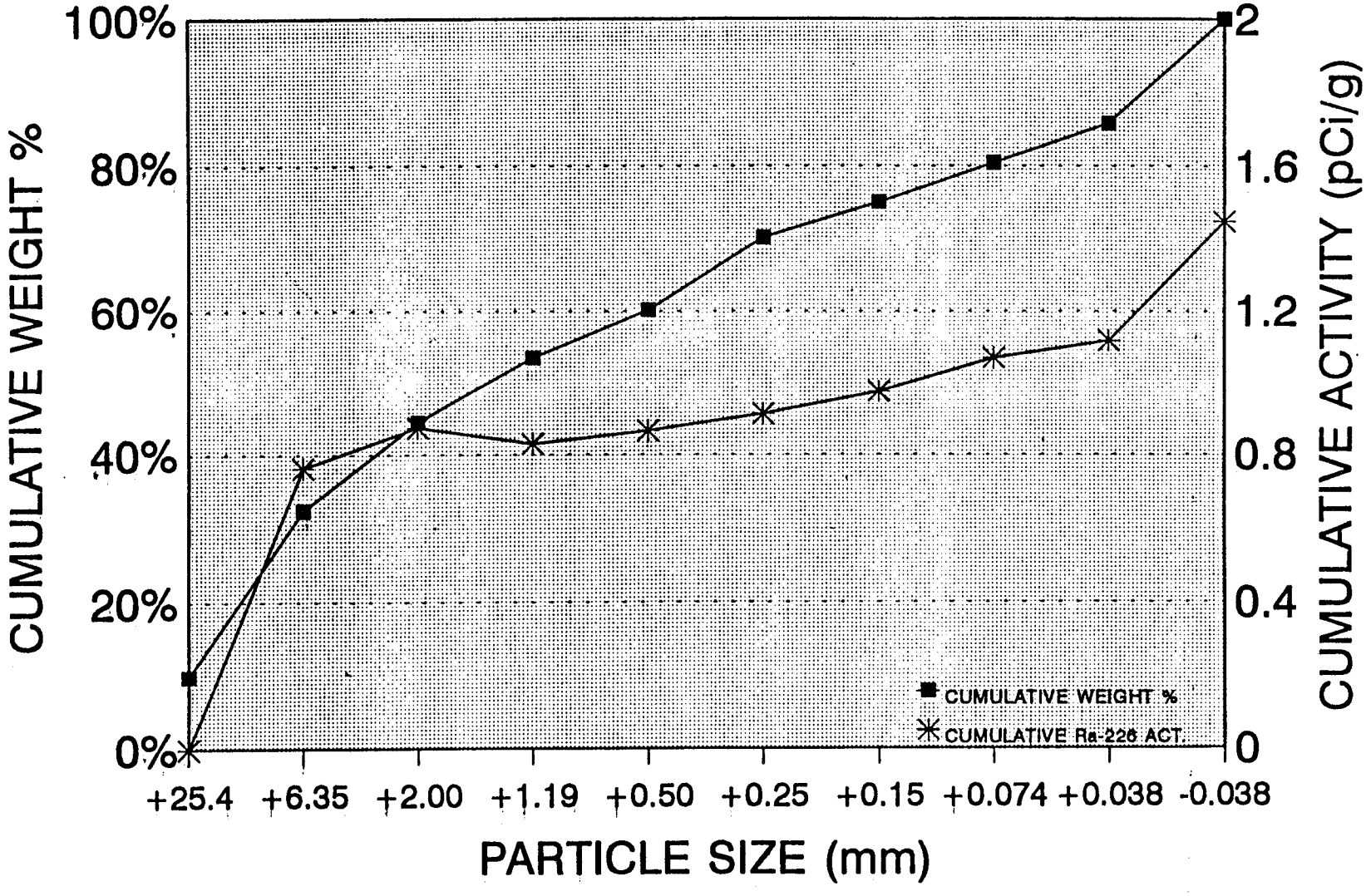

FIGURE 8-2

*Removed One Ra-226 Source From Sample

SOIL SAMPLE C

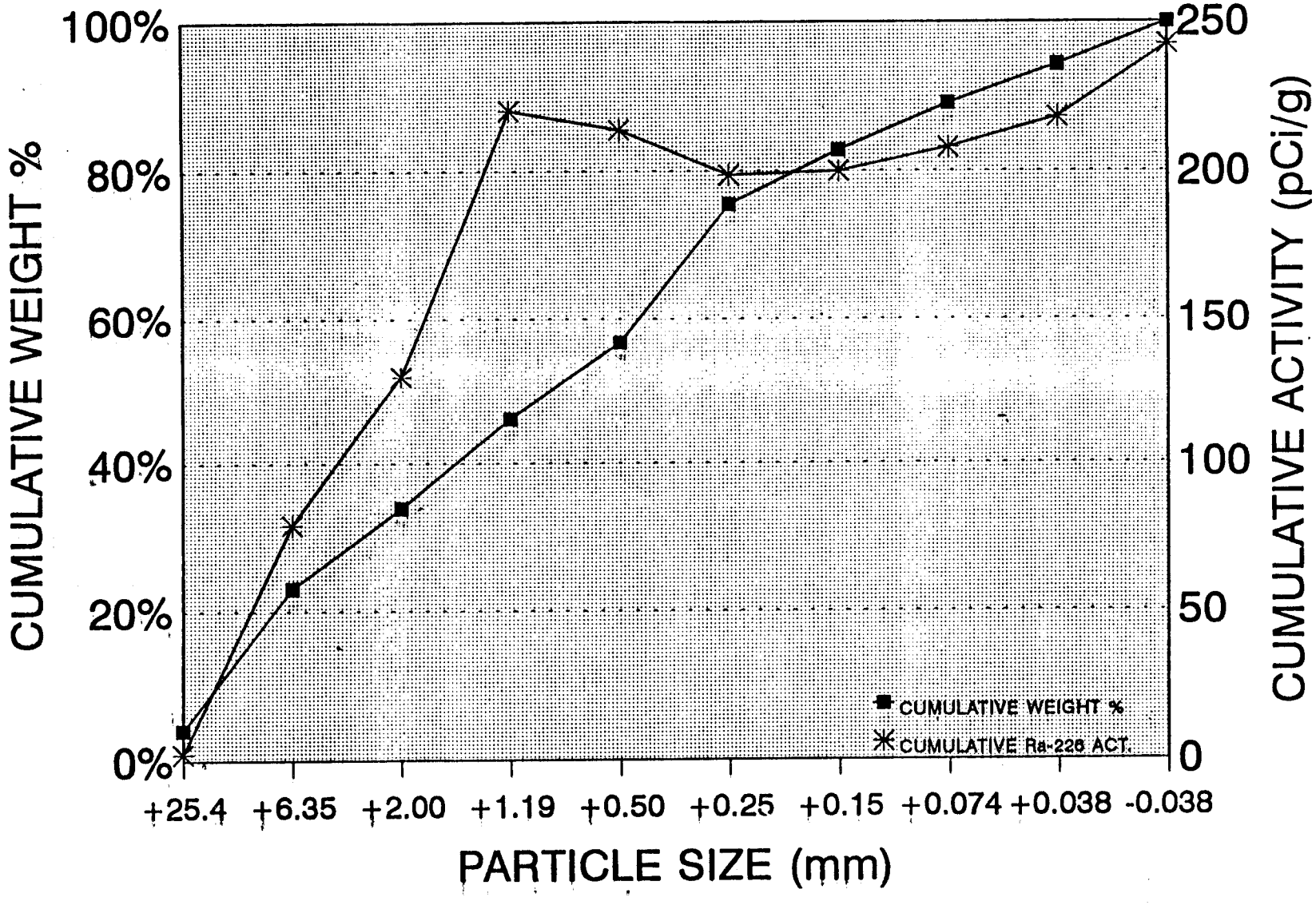

FIGURE 3-3

3.2.2 Radionuclide Distribution

Based on previous findings at the site, the radioactivity was expected to be due to the presence of sources (buttons) containing radium-226 or source fragments larger than most soil particles (>16 mesh, 1.19 mm). Therefore, the particle-size fractions from wet sieving were combined into three major fractions to minimize the expenditure for their detection by radioanalysis: a +16-mesh fraction, produced by combining the +¼-in, -¼-in/+8, and -8/+16-mesh fractions; a -16/+200-mesh fraction, produced from the -16/+30, -30/+60, -60/+100, and -100/+200-mesh fractions, and a -200-mesh fraction. The particle-size distributions of the combined fractions are reported in Tables 3-7 through 3-16 in Appendix A. These combined fractions were analyzed by gamma spectrometry. Each whole soil aliquot and the combined fractions contain less than 1 pCi/g radium-228. The radium-226 concentrations of the whole soil aliquots and each combined particle-size fraction are presented in Tables 3-7 through 3-16 and summarized in Table 3-6 (Appendix A). The wash water from the vigorous wash and wet-sieving procedures contained less than the MDCs of radium-226 and radium-228. The MDCs ranged from 64 to 100 pCi/L of radium-226 and from 15 to 19 pCi/L of radium-228, which are below the acceptable limits for release into the sanitary sewer.

4.0 DISCUSSION

4.1 Soil Samples A, B, and C

4.1.2 Particle-Size Distribution

Soil samples A, B, and C were soaked for 12 hr, rather than vigorously washed, before wet sieving to minimize the possibility of fragmentation of larger source particles. The data from the three samples (Tables 3-1, 3-2, and 3-3) reveal that their particle-size distributions are similar. Approximately 80 to 90 percent by weight of the soil is in the sand or gravel size-fractions, with about one-third being gravel. Sample B is an outlier in the three samples with approximately 50 percent more +¼-in particles than either A or C. Sample C contains half as much -200-mesh particles but more material in the -8/+60-mesh fractions than A and B. Vigorous washing before wet sieving would generate more fines, but the particle-size distribution probably would not shift to a dramatically larger quantity of fines. Wet sieving after vigorously washing soil samples, as performed on samples D-M, reveals more about the suitability of these soils for a potential remediation effort.

4.1.3 Radionuclide Distribution

Gamma analysis of each of three aliquots of soil samples A, B, and C (Tables 3-1, 3-2, and 3-3) and for the combined fractions (Table 3-5) indicates that soil sample A consists of two aliquots with very similar radium-226 concentrations, 242 and 232 pCi/g, and a third aliquot with 481 pCi/g; the average of the three aliquots is, however, 318 pCi/g (Table 3-1). These results suggests that soil sample A is not homogeneous. The apparent inhomogeneity, can be explained by the exceptionally high activity of the -2.00/+1.19-mm size fraction with a radium-226 concentration of 1160 pCi/g. Subsequent examination of this fraction revealed a single particle, between 1 and 2 mm in diameter, with very high activity as indicated by a hand-held survey meter. The weighted average of the radium-226 concentration of the remaining fractions, excluding the -2.00/+1.19-mm fraction, is 287 pCi/g, similar to that of the other two aliquots and more in line with the average of the aliquots of soil C. Soil sample C consists of three aliquots with similar radium-226 concentrations, 179, 190, and 228 pCi/g, with an average of 199 pCi/g. These results indicate that soil sample C is homogenous. Soil sample B presents a significant contrast; the first and third aliquots contain a radium-226 concentration of approximately 1 pCi/g while the second aliquot

contains 2350 pCi/g. It was found that the second aliquot contained an identifiable radium-226 source, a single fragment of a radium button (see Table 3-2). After the source fragment was removed, the radium-226 concentration of the aliquot was also about 1 pCi/g. This finding indicates that virtually all the activity in soil sample B was concentrated in the radium source, and once removed, the remaining soil had an activity that is considered to be background level (1 to 3 pCi/g radium-226). Also, after the source was removed, the results indicate homogeneity for soil sample B. The radionuclide distribution of the particle-size fractions of soil samples A, B, and C are very similar to each other (Table 3-1, 3-2, 3-3 and Figure 3-1, 3-2, 3-3). Radium-226 is distributed relatively evenly among the fractions with the exception of the lower concentration of the two larger sized fractions (+1-in and -1/+¼-in) and the higher concentration in the fine fraction (-400-mesh). The notable difference between the three soil samples is the very low radium-226 concentrations in the whole soils and particle-size fractions of soil sample B once the source was removed.

If sample B is representative of the site, the site would be relatively easy to remediate by removing the highly radioactive source particles, as was done in one aliquot before sieving. In contrast, with the even distribution and higher concentration of radium-226 found in the fractions of soil samples A and C, vigorous washing and wet sieving alone would not be a recommended remediation method. Should these soil samples be representative of the Parcel E site, additional physical and chemical characterization, such as density tests and/or chemical extraction studies, would be required to identify an alternate property of the soil particles or their contaminant to exploit for remediation.

The result from the preliminary examination of soil samples A, B, and C from Hunter's Point Annex, Parcel E indicated the presence of only two types of contaminated soils: one that contains a radium-226 source or source fragment (a button) larger than 16 mesh (1.19 mm) and another soil with high concentrations of radium-226, approximately evenly distributed, among the particle-size fractions. These three samples were taken at locations known to contain large sources and were not considered sufficient to reveal the actual radionuclide characteristics of the site, especially with the suspected history of contamination by single, larger sized sources (>1.19 mm) (DEA94). No conclusion can be drawn from these data regarding the existence and distribution of radium-226 away from the immediate site of identified sources.

4.2 Soil Samples D-M

Ten additional soil samples D-M were collected to obtain a better understanding of the distribution of radium-226 in the soil of the Parcel E area. The preliminary study of soil samples A, B, and C indicated two types of radium-226 distributions in the soil: a volume of soil containing a single, highly radioactive source larger than 16 mesh (1.19 mm) that otherwise contains radium-226 at background concentrations (see Table 3-2); and a volume of soil with high concentrations of radium-226, approximately evenly distributed among the particle-size fractions (see Tables 3-1 and 3-3). To what extent either of these two distributions or some other radium-226 distribution(s) represent the contamination of the Parcel E area was not known when the results of the preliminary study were first reported. These ten samples were collected in a manner to determine if and to what extent radium contamination was present in site soils away from the immediate location of a source easily identified by a gamma survey meter.

Three general types of soil samples were collected from the site (see Table 2-1): one sample, at an identified source location (H); seven samples at three, five, or ten feet away from a source (D, E, F, G, I, J, and K); and two samples away from any identified source areas (L and M).

4.2.1 Particle-Size Distribution

An extensive examination of the particle-size distribution for soil samples D-M was not the primary purpose of this study. For effective sieving in a reasonable period of time, seven sieves were used producing eight size-fractions. The sieving results are presented in this report (Table 3-4) to provide all the data on the soil samples in the event that site remediation by particle-size separation is considered.

The particle-size distributions of the ten samples are very similar except for sample M. Like soil samples A, B, and C, which were not vigorously washed, (Tables 3-1, 3-2, and 3-3), approximately 80 to 90 percent by weight of the soil in nine of the ten samples is in the sand to gravel-sized fractions with about one-third in the gravel fraction. Sample M, however, contains mostly small particles with approximately 88 percent in the -200-mesh fraction. Sample F contains half as much -200-mesh material, compared to the remaining eight samples, with more material in the ¼-in/+8-mesh fraction. Sample F is similar to soil

sample C examined earlier. Except for samples F and M, the other eight samples are similar to sample A examined in the first study.

Site remediation using a hydroseparation and/or wet-sieving process, should it prove beneficial, could be performed with typical mineral processing equipment. Since there is only a low percentage of clay-sized particles, clay particles would present little hinderance. The large quantity of sand and gravel particles would be relatively easy to process.

4.2.2 Radionuclide Distribution

In an attempt to better understand the area distribution of radium-226 contamination and to determine the possibility of finding larger source-particles among the +16-mesh (+1.19-mm) soil fractions, ten soil samples, described above in Section 2.1.2, were collected in September 1993 and sent to NAREL for study.

In order to determine the presence of contaminated particles among the larger soil particles (+16-mesh or +1.19-mm) and additional contaminated smaller sized fractions, especially -200-mesh (-0.074-mm), the eight particle-size fractions produced by wet sieving were combined into three size fractions, +16, -16/+200, and -200-mesh, before performing the analyses by gamma spectrometry. The results of these analyses indicate that only two soil samples (G and H) contain elevated concentrations of radium-226 (Tables 3-6 through 3-16). The remaining eight samples contain only background concentrations of radium-226. None of the ten samples contains concentrations above background of radium-228 (0.3 to 0.7 pCi/g), indicating that the activity in the site soils at Hunter's Point Annex is from natural radionuclides and at background levels other than that attributable to radium-226 point sources (DEA94; SCA94).

Sample H represents soil collected at the location of a radium-226 source, but does not contain the source. The average concentration of radium-226 is 17.8 pCi/g. Much of the activity is in the smaller sized soil particles, indicating some release of the contamination possibly by fragmentation and/or oxidation of the source. Sample G, collected five feet from sample H, contains the highest concentration of radium-226 with the concentration inversely proportional to particle size, also indicating fragmentation and/or oxidation of a source. Assuming a source was not previously located at this point, the elevated concentration of radium-226 may be the result of fragmentation of the source at location H.

Since eight of the ten samples were collected away from a source and contain only background concentrations of radium-226, they may represent a significant area of the site with only background levels of radium-226. However, regions around a source, even after the source is mechanically removed, may contain elevated concentrations of radium-226, as indicated by the radium concentrations in samples G and H.

5.0 CONCLUSIONS

Three soil samples (A, B, and C) from the Hunter's Point Annex, Parcel E, were received at NAREL in July 1993 for preliminary study to determine their radionuclide content and particle-size and radionuclide distributions. After examination of the results from those samples, ten more samples (D-M) were collected in September 1993 and sent to NAREL for study to obtain a better understanding of the distribution of radium-226 in the soil particle-sizes, determine if large radium-226 sources or their fragments (>16 mesh, 1.19 mm) are present among the soil particles, and determine if significant contamination is present in soil away from the immediate source location.

The particle-size distributions of soil samples A, B, and C (Tables 3-1, 3-2, and 3-3) and D-L (Table 3-4) are similar, with approximately 80 to 90 percent by weight of the soil particles in the sand-to-gravel size fractions and about one-third being in gravel material exclusively. Sample M (Table 3-4) is the exception with most particles (88 percent) in the -200-mesh (-0.074-mm) fraction. Based on the particle-size distribution of the thirteen soil samples (with the exception of sample M), the results of this study indicate that particle-size separation could be accomplished by hydroclassification and/or sieving with units typically used in the mineral processing industry.

Soil samples A and C contain elevated concentrations of radium-226 (Tables 3-1 and 3-3, respectively) evenly distributed among the particle-size fractions with the single exception of the -2.00/+1.19-mm fraction of sample A. In contrast, sample B contained background concentrations of radium-226 once the source was removed. This indicates that the activity in sample B is primarily in the source and that no release of contamination occurred by fragmentation and/or oxidation of the source.

Eight of the ten soil samples in the second set (D-F and I-M) contain background concentrations of radium-226. Sample H, which was collected at a source location, contains elevated concentrations. Sample G, taken five feet away from the location of sample H, has the highest concentration of radium-226 (Tables 3-7 to 3-16 and Table 3-6). Much of the activity of both samples is in the smaller sized fractions, indicating some release of contamination from a source possibly by fragmentation and/or oxidation of the source.

Since eight of the ten samples that were collected away from a source contain background concentrations of radium-226, they may represent a significant volume of the soil at the Parcel E site with only background levels of radium-226. Remediation of the site might be accomplished, therefore, by selective removal of soil in the vicinity of identifiable sources.

Overall, the limited number of samples considered in these studies suggest that a significant volume of the Hunter's Point Annex, Parcel E site could potentially be remediated by a combination of selective removal of soil in the vicinity of identifiable sources and removal of the source from the soil by particle-size separation.

6.0 REFERENCES

DEA94 Dean, S.M., "Radium Issues at Hunter's Point Annex," WM'94, Tucson, AZ, February 27 - March 3, 1994.

EPA80a U.S. Environmental Protection Agency, "Prescribed Methods for Measurement of Radioactivity in Drinking Water, Gamma Emitting Radionuclides, Method 901.1," EPA-600/4-80-032, August 1980.

SCA91a S. Cohen and Associates, Inc., "Procedure for Vigorous Washing of Soil Samples," SCA-301, January 1991.

SCA91b S. Cohen and Associates, Inc., "Procedure for Separating Soils by Particle Size - Hand Sieving," SCA-401, January 1991.

SCA94 S. Cohen and Associates, Inc., "Hunter's Point Annex - Parcel B Report," for Office of Radiation and Indoor Air, National Air and Radiation Environmental Laboratory, Montgomery, Alabama, Contract No. 68D20155, April 1994.

APPENDIX A
TABLES

TABLE 2-1 DESCRIPTION OF SOIL SAMPLES COLLECTED AT PARCEL E

Soil Sample[1]	Geographical Location	Exposure Rate at Location (μR/hr)[2]	Description
A	37° 43.236' N 122° 22.468' W	8	Source A
B	37° 43.249' N 122° 27.430' W	7	Source B
C	37° 43.193' N 122° 22.474' W	8	Source C
D	37° 43.259' N 122° 22.497' W	8	5 ft west of where Sample C had been collected
E	37° 43.235' N 122° 22.532' W	6	Vicinity of multiple identifiable sources - 8 to 10 ft removed from any source
F	37° 43.235' N 122° 22.486' W	5	Vicinity of multiple identifiable sources - 8 to 10 ft removed from any source
G	37° 43.280' N 122° 22.409' W	20	5 to 6 ft removed from Source H location
H	37° 43.241' N 122° 22.517' W	45	Source H
I	37° 43.280' N 122° 22.477' W	7	3 ft west of where Sample C had been collected
J	37° 43.246' N 122° 22.499' W	5	3 ft from where Sample A had been collected
K	37° 43.244' N 122° 22.485' W	6	5 ft from where Sample A had been collected

TABLE 2-1 (continued)

Soil Sample[1]	Geographical Location	Exposure Rate at Location (μR/hr)[2]	Description
L	37° 43.248' N 122° 22.479' W	10	Well removed from any identifiable source
M	37° 43.257' N 122° 22.498' W	4	Well removed from any identifiable source

(1) Soil samples A, B, and C were collected July 1993; samples D-M were collected September 1993.

(2) Exposure rates at all locations were measured during the second collection visit (September 1993) after soil samples A, B, and C had been collected in July 1993.

TABLE 3-1 PARTICLE-SIZE AND RADIONUCLIDE DISTRIBUTION OF SOIL SAMPLE A

Size (mm)	Weight Percent	Cumulative Weight Percent	Ra-226 (pCi/g-dry)	Cumulative Ra-226 (pCi/g-dry)
Whole	100.00	100.00	242	
Whole	100.00	100.00	481	
Whole	100.00	100.00	232	
			318(1)	
+25.4	4.44	4.44	9.8 ± 1.5(2)	9.8
-25.4/+6.35	15.35	19.78	68.8 ± 1.6	55.6
-6.35/+2.00	13.34	33.13	116 ± 3	79.9
-2.00/+1.19	10.45	43.58	1160 ± 26	338.9
-1.19/+0.50	8.78	52.35	409 ± 6	350.7
-0.50/+0.25	12.56	64.92	384 ± 6	357.1
-0.25/+0.15	6.37	71.28	321 ± 6	353.9
-0.15/+0.074	6.67	77.96	356 ± 5	354.1
-0.074/+0.038	5.47	83.43	395 ± 8	356.8
-0.038	16.57	100.00	486 ± 8	378.2
	100.00(3)			
	99.54(4)			

(1) Average radium-226 concentration of the three whole-soil aliquots

(2) ± 2-sigma counting error

(3) Sum of weight percent column for the particle-size fractions

(4) Percent recovery of soil after sieving

TABLE 3-2 PARTICLE-SIZE AND RADIONUCLIDE DISTRIBUTION OF SOIL SAMPLE B

Size (mm)	Weight Percent	Cumulative Weight Percent	Ra-226 (pCi/g-dry)	Cumulative Ra-226 (pCi/g-dry)
Whole	100.00	100.00	1.15	
Whole	100.00	100.00	2350	
Whole	100.00	100.00	0.83	
			0.99(1)	
+25.4	9.93	9.93	<0.486	<0.486
-25.4/+6.35	22.51	32.44	1.10 ± .51(2)	0.76
-6.35/+2.00	11.94	44.38	1.17 ± 0.46	0.87
-2.00/+1.19	9.03	53.41	0.61 ± 0.49	0.82
-1.19/+0.50	6.72	60.13	1.15 ± 0.59	0.86
-0.50/+0.25	10.04	70.17	1.19 ± 0.57	0.91
-0.25/+0.15	4.93	75.10	1.87 ± 1.06	0.97
-0.15/+0.074	5.36	80.46	2.38 ± 0.88	1.07
-0.074/+0.038	5.38	85.84	1.85 ± 0.90	1.12
-0.038	14.16	100.00	3.46 ± 0.77	1.45
	100.00(3)			
	98.18(4)			

(1) Average radium-226 concentration of the two whole-soil aliquots; 2350 pCi/g aliquot was not used since this high activity was the result of a source fragment and was removed before sieving. Note: radium-226 concentration of the fractions are the result of sieving all three aliquots after the source was removed from the second aliquot.

(2) ± 2-sigma counting error

(3) Sum of weight percent column for the particle-size fractions

(4) Percent recovery of soil after sieving

TABLE 3-3 PARTICLE-SIZE AND RADIONUCLIDE DISTRIBUTION OF SOIL SAMPLE C

Size (mm)	Weight Percent	Cumulative Weight Percent	Ra-226 (pCi/g-dry)	Cumulative Ra-226 (pCi/g-dry)
Whole	100.00	100.00	179	
Whole	100.00	100.00	190	
Whole	100.00	100.00	228	
			199(1)	
+25.4	4.08	4.08	2.17 ± 0.91(2)	2.17
-25.4/+6.35	19.03	23.10	95.6 ± 2.5	79.1
-6.35/+2.00	10.70	33.81	239 ± 5	130
-2.00/+1.19	12.20	46.01	471 ± 6	220
-1.19/+0.50	10.72	56.72	186 ± 3	214
-0.50/+0.25	18.82	75.54	153 ± 4	199
-0.25/+0.15	7.22	82.76	213 ± 4	200
-0.15/+0.074	6.30	89.06	312 ± 5	208
-0.074/+0.038	5.18	94.25	394 ± 9	218
-0.038	5.75	100.00	642 ± 11	242
	100.00(3)			
	99.78(4)			

(1) Average radium-226 concentration of the three whole-soil aliquots

(2) ± 2-sigma counting error

(3) Sum of weight percent column for the particle-size fractions

(4) Percent recovery of soil after sieving

TABLE 3-4 PARTICLE-SIZE DISTRIBUTION OF SOIL SAMPLES D-M

Weight Percent

Size (mm)	Weight Percent									
	D	E	F	G	H	I	J	K	L	M
+6.35	25.80	21.03	25.11	14.16	18.13	23.49	23.28	34.00	24.06	0.80
-6.35/+2.00	8.22	8.79	27.79	12.61	12.15	9.19	9.22	8.40	5.80	0.86
-2.00/+1.19	6.06	7.60	13.08	12.68	10.21	8.48	8.10	11.41	9.94	3.19
-1.19/+0.50	10.15	6.95	6.92	10.29	8.71	7.74	9.05	5.84	12.65	3.06
-0.50/+0.25	13.53	14.36	7.74	12.30	11.31	12.89	12.25	6.95	15.45	2.11
-0.25/+0.15	7.14	7.73	3.31	6.44	6.25	7.11	6.77	3.97	6.86	0.73
-0.15/+0.074	7.35	7.34	3.05	7.36	7.45	7.54	7.40	5.62	6.96	1.41
-0.074	21.77	26.21	13.00	24.17	25.79	23.56	23.92	23.83	18.28	87.83
	100.00[1]	100.01	100.00	100.00	100.00	100.00	99.99	100.02	100.00	99.97
	100.16[2]	99.84	99.47	99.51	97.12	100.03	102.29	100.91	98.35	99.23

(1) Sum of weight percent column for the particle-size fractions

(2) Percent recovery of soil after sieving

TABLE 3-5 RADIUM-226 ACTIVITY IN WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLES A, B, AND C

Size (mm)	Ra-226 (pCi/g-dry)		
	A	B	C
Whole[1]	318	0.99	199
+1.19[2]	339	0.82	220
-1.19/+0.074	373	1.54	195
-0.074	403	3.02	524

(1) Radium-226 activity is the average of three whole-soil aliquots.

(2) Radium-226 activities of combined fractions for samples A, B, and C are the weighted average of activities of individual fractions presented in Tables 3-1, 3-2, and 3-3, respectively.

TABLE 3-6 RADIUM-226 ACTIVITY IN WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLES D-M

Size (mm)	Ra-226 (pCi/g-dry)									
	D	E	F	G	H	I	J	K	L	M
Whole[1]	1.40	1.43	1.21	63.90	17.80	1.86	0.95	0.75	1.54	0.26
+1.19[2]	1.06	0.08	0.23	12.80	7.14	1.49	0.58	0.65	1.17	0.54
-1.19/+0.074	1.09	1.25	1.03	79.40	14.10	1.57	0.94	0.69	1.28	0.55
-0.074	2.28	2.05	5.20	287.00	48.70	3.37	2.57	1.48	3.62	0.41

(1) Radium-226 activity is the average of three whole-soil aliquots.

(2) Radium-226 activities of combined fractions for samples D-M are measured values presented in Tables 3-7 through 3-16, respectively.

TABLE 3-7 RADIONUCLIDE AND PARTICLE-SIZE DISTRIBUTION OF WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLE D

Size (mm)	Weight Percent	Ra-226 (pCi/g-dry)
Whole	100.00	1.51 ± 0.29[1]
Whole	100.00	1.61 ± 0.25
Whole	100.00	1.09 ± 0.21
		1.40[2] ± 0.25
+1.19	40.52	1.06 ± 0.20
-1.19/+0.074	38.55	1.09 ± 0.20
-0.074	20.94	2.28 ± 0.36
	100.01[3]	

(1) ± 2-sigma counting error

(2) Average radium-226 concentration of the three whole-soil aliquots

(3) Sum of weight percent column for the particle-size fractions

TABLE 3-8 RADIONUCLIDE AND PARTICLE-SIZE DISTRIBUTION OF WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLE E

Size (mm)	Weight Percent	Ra-226 (pCi/g-dry)
Whole	100.00	1.59 ± 0.20[1]
Whole	100.00	1.49 ± 0.18
Whole	100.00	1.20 ± 0.13
		1.43[2] ± 0.17
+1.19	37.41	0.08 ± 0.22
-1.19/+0.074	36.21	1.25 ± 0.30
-0.074	26.38	2.05 ± 0.28
	100.00[3]	

(1) ± 2-sigma counting error

(2) Average radium-226 concentration of the three whole-soil aliquots

(3) Sum of weight percent column for the particle-size fractions

TABLE 3-9 RADIONUCLIDE AND PARTICLE-SIZE DISTRIBUTION OF WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLE F

Size (mm)	Weight Percent	Ra-226 (pCi/g-dry)
Whole	100.00	1.47 ± 0.20[1]
Whole	100.00	1.24 ± 0.33
Whole	100.00	0.93 ± 0.14
		1.21[2] ± 0.22
+1.19	66.06	0.23 ± 0.08
-1.19/+0.074	21.04	1.03 ± 0.24
-0.074	12.90	5.20 ± 0.43
	100.00[3]	

(1) ± 2-sigma counting error

(2) Average radium-226 concentration of the three whole-soil aliquots

(3) Sum of weight percent column for the particle-size fractions

TABLE 3-10 RADIONUCLIDE AND PARTICLE-SIZE DISTRIBUTION OF WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLE G

Size (mm)	Weight Percent	Ra-226 (pCi/g-dry)
Whole	100.00	31.90 ± 0.20[1]
Whole	100.00	95.90 ± 1.39
		63.90[2] ± 1.06
+1.19	39.51	12.80 ± 0.51
-1.19/+0.074	36.37	79.40 ± 1.16
-0.074	24.12	287.00 ± 1.96
	100.00[3]	

(1) ± 2-sigma counting error

(2) Average radium-226 concentration of the whole-soil aliquots

(3) Sum of weight percent column for the particle-size fractions

TABLE 3-11 RADIONUCLIDE AND PARTICLE-SIZE DISTRIBUTION OF WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLE H

Size (mm)	Weight Percent	Ra-226 (pCi/g-dry)
Whole	100.00	18.80 ± 0.62[1]
Whole	100.00	16.80 ± 0.48
		17.80[2] ± 0.55
+1.19	40.58	7.14 ± 0.34
-1.19/+0.074	33.77	14.10 ± 0.49
-0.074	25.65	48.70 ± 0.93
	100.00[3]	

(1) ± 2-sigma counting error

(2) Average radium-226 concentration of the whole-soil aliquots

(3) Sum of weight percent column for the particle-size fractions

TABLE 3-12 RADIONUCLIDE AND PARTICLE-SIZE DISTRIBUTION OF WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLE I

Size (mm)	Weight Percent	Ra-226 (pCi/g-dry)
Whole	100.00	2.01 ± 0.18[1]
Whole	100.00	1.70 ± 0.29
		1.86[2] ± 0.24
+1.19	41.22	1.49 ± 0.23
-1.19/+0.074	35.36	1.57 ± 0.25
-0.074	23.42	3.37 ± 0.37
	100.00[3]	

(1) ± 2-sigma counting error

(2) Average radium-226 concentration of the whole-soil aliquots

(3) Sum of weight percent column for the particle-size fractions

TABLE 3-13 RADIONUCLIDE AND PARTICLE-SIZE DISTRIBUTION OF WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLE J

Size (mm)	Weight Percent	Ra-226 (pCi/g-dry)
Whole	100.00	1.06 ± 0.21[1]
Whole	100.00	0.84 ± 0.17
		0.95[2] ± 0.19
+1.19	40.64	0.58 ± 0.23
-1.19/+0.074	35.46	0.94 ± 0.22
-0.074	23.91	2.57 ± 0.33
	100.00[3]	

(1) ± 2-sigma counting error

(2) Average radium-226 concentration of the whole-soil aliquots

(3) Sum of weight percent column for the particle-size fractions

TABLE 3-14 RADIONUCLIDE AND PARTICLE-SIZE DISTRIBUTION OF WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLE K

Size (mm)	Weight Percent	Ra-226 (pCi/g-dry)
Whole	100.00	0.74 ± 0.18[1]
Whole	100.00	0.76 ± 0.17
		0.75[2] ± 0.18
+1.19	53.70	0.65 ± 0.15
-1.19/+0.074	22.58	0.69 ± 0.26
-0.074	23.72	1.48 ± 0.26
	100.00[3]	

(1) ± 2-sigma counting error

(2) Average radium-226 concentration of the whole-soil aliquots

(3) Sum of weight percent column for the particle-size fractions

TABLE 3-15 RADIONUCLIDE AND PARTICLE-SIZE DISTRIBUTION OF WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLE L

Size (mm)	Weight Percent	Ra-226 (pCi/g-dry)
Whole	100.00	1.48 ± 0.19[1]
Whole	100.00	1.59 ± 0.17
		1.54[2] ± 0.18
+1.19	40.59	1.17 ± 0.24
-1.19/+0.074	41.41	1.28 ± 0.15
-0.074	18.00	3.62 ± 0.33
	100.00[3]	

(1) ± 2-sigma counting error

(2) Average radium-226 concentration of the whole-soil aliquots

(3) Sum of weight percent column for the particle-size fractions

TABLE 3-16 RADIONUCLIDE AND PARTICLE-SIZE DISTRIBUTION OF WHOLE SOIL AND COMBINED FRACTIONS OF SOIL SAMPLE M

Size (mm)	Weight Percent	Ra-226 (pCi/g-dry)
Whole	100.00	0.19 ± 0.11[1]
Whole	100.00	0.33 ± 0.17
		0.26[2] ± 0.14
+1.19	4.90	0.54 ± 0.58
-1.19/+0.074	7.34	0.55 ± 0.22
-0.074	87.75	0.41 ± 0.15
	99.97[3]	

(1) ± 2-sigma counting error

(2) Average radium-226 concentration of the whole-soil aliquots

(3) Sum of weight percent column for the particle-size fractions